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A New Routing Algorithm for Hierarchical Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) have become an interesting area to researchers in recent years due to the low cost of sensor nodes, wide application areas and with low or no cost of maintenance after deployment in a target area. In some sensor system applications, the nodes are hard to reach and it is impossible to replace their batteries. So the nodes must operate without battery replacement for a long time. Such conditions make the system power consumption a very crucial parameter. Thus, Clustering is an energy efficient way that divides sensor nodes into many clusters, each of which has a cluster head. In this paper a new cluster-based routing algorithm for hierarchical WSNs has been proposed to select an alternative node to get replaced in place of node which loses its energy such that it extends the lifetime of entire network and avoids data loss. The simulation results show that, for large scale WSNs, our proposed algorithm performs better than the typical existing routing algorithms in terms of network lifetime.

Keywords: WSN, Sensor, Cluster Head, LEACH-like protocols, Alternative node.

خوارزمية توجيه جديدة لشبكات الاستشعار اللاسلكية الهرمية

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الملخص

أصبحت شبكات الاستشعار اللاسلكية (WSNs) منطقة مثيرة للاهتمام للباحثين في السنوات الأخيرة نظرا لانخفاض تكلفة عقد الاستشعار، ومجالات التطبيق واسعة وبتكلفة منخفضة أو معدومة الصيانة بعد النشر في المنطقة المستهدفة. في بعض تطبيقات انظمة الاستشعار، فان بعض العقد من الصعب الوصول إليها ،أو من المستحيل أن يتم تبديل البطاريات الخاصة بهم. وبالتالي فإن العقد يجب أن تعمل دون استبدال البطارية لفترة طويلة. هذه الظروف تجعل استهلاك طاقة النظام مسالة حاسمة جدا. وبالتالي، التجمع هو وسيلة كفؤه في استخدام الطاقة الذي يقسم العقد الاستشعار في العديد من مجموعات، كل منها له رأس المجموعة. في هذه الورقة تم اقتراح خوارزمية التوجيه القائم على كتلة جديدة ل WSNsالهرمية تدعى العقدة البديلة للحصول على استبدال بدلا من العقدة التي يفقد طاقته بحيث يمتد عمر الشبكة بالكامل ويتجنب فقدان البيانات. وتشير نتائج المحاكاة أنه ل WSNsعلى نطاق واسع، الخوارزمية المقترحة أداء أفضل من خوارزميات التوجيه النموذجية الموجودة من حيث العمر الشبكة.

الكلمات المفتاحية : أجهزة الاستشعار ،شبكات التحسس اللاسلكية, رئيس الكتلة, البروتوكولات الشبيهة LEACH ، العقدة البديلة.

1. Introduction

Wireless sensor networks (WSNs) have significant impact upon the efficiency of military and civil applications, which may be generally classified into two classes: data collection and surveillance [1].For data collection, the scientist, for example an environmental specialist, would want to collect data from thousands of points spread throughout the area to recognize any changing in the environment to keep the condition under control. In huge systems such as assembly lines, shuttles, and airplanes, the sensor network could help the engineers to monitor the system by periodically collecting data about the system's modules. Surveillance applications deploy sensor nodes by placing them at fixed locations throughout an environment. All nodes continuously monitor the environment, and when there is an abnormal, they send reports to the base station. In any application there are some challenges to face the sensor nodes in WSNs such as small size of sensor nodes, Overlapping sensing areas, frequent change of network topology and wireless link. To overcome the challenges listed above, it is desirable to build a sensor network that employs multi-hop communication and is reconfigurable, and organizing (including re-routing, redundancy reduction, and sensor deployment).

2.Clustering in Wireless Sensor Networks

Grouping sensor nodes into clusters has been widely pursued by the research community in order to achieve the network scalability objective. Every cluster has a leader, often referred to as the cluster-head (CH). The cluster membership may be fixed or variable. Of the benefit, clustering may conserve communication bandwidth since it limits the scope of inter-cluster interactions to CHs and avoids redundant exchange of messages among sensor nodes. Moreover, a CH can aggregate the data collected by the sensors in its cluster and thus decrease the number of relayed packets [2][6]. The LEACH (Low-Energy Adaptive Clustering Hierarchy) algorithm [3] is a well-known clustering algorithm for WSNs of cluster-based architecture, by selecting the CHs in a round changing mechanism. LEACH achieves improvement compared to direct transmissions, as measured in terms of nodes' lifetime. Following the idea of LEACH algorithm, a number of algorithms have been presented such as PEGASIS (Power-Efficient Gathering in Sensor Information Systems) [10], TEEN (a Routing Protocol for Enhanced Efficiency in Wireless Sensor Networks) [11], APTEEN (A Hybrid Protocol for Efficient Routing and Comprehensive Information Retrieval in Wireless Sensor Networks) [12], PEACH (Power-efficient and adaptive clustering hierarchy protocol for wireless sensor networks) [13] and an energy efficient hierarchical clustering algorithm for wireless sensor networks [14], which use the same concept with LEACH. In this paper, we call this kind of cluster-based routing algorithms as LEACH-like protocols. However, the routing issue has not been well studied in these LEACH-like algorithms. Because non-CH sensor nodes in a cluster use the CH as the intermediary to the base station (BS), but for CH sensor nodes, there is nearly no routing algorithm for them to transmit with the BS. Also in LEACH-like protocols, it is assumed all sensor nodes could communicate with the BS using large transmission power. It is unachievable in real world large range WSNs, because of not only the constrained range of transmission in IEEE 802.15.4 for WSNs, but also the constraints of radio transmit equipment [5][6].

3.Routing Algorithms in WSNs protocols

In general, routing in WSNs can be divided into the following types depending on the network structure [7].

- **Flat-based routing**, all nodes are typically assigned equal roles or functionality to perform the sensing and gathering tasks [8][9].
- **Cluster-based routing**, nodes will play different roles in the network; certain nodes are used to process and send the information, while other nodes are used to perform the sensing of the target [3][11].
- **Location-base routing**, sensor nodes positions are exploited to route data in the network. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths [15][16].

Also routing in WSNs can be divided into ***multipath-based***, ***query-based***, ***negotiation-based***, ***QoS-based*** and ***coherent-based*** routing techniques depending on the algorithm operation [6][7] depending on protocol operation. The classification of routing protocols is shown in Figure 1.

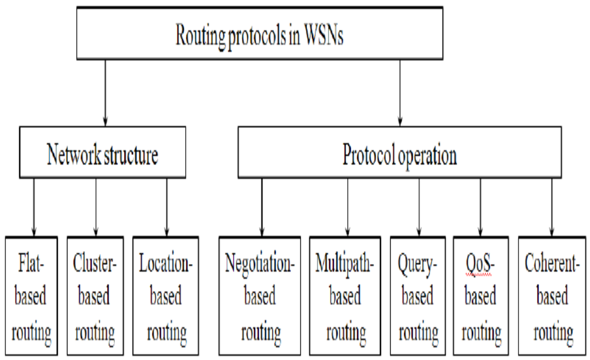

Figure 1: Classification of routing in WSNs

Since this paper is working on the cluster-based routing algorithm, we focus on the categories in network structure.

3.1Cluster-based Routing

Cluster-based routing, originally proposed in wireline networks, are well-known techniques with special advantages related to scalability and efficient communication. As such, the concept of cluster-based routing is also utilized to perform energy-efficient routing in WSNs. In this architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads (CH) can greatly contribute to overall system scalability, lifetime, and energy efficiency. Cluster-based routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select CHs and the other layer is used for routing. However, most transmission algorithms provided in cluster-based routing are little about routing, rather, focusing on the method of clustering the sensor nodes, from which leads us to propose the new routing algorithm for cluster-based WSNs in this thesis [6][7].

3.2 LEACH-like protocols for clustering

The classic cluster-based algorithm called LEACH (Low-Energy Adaptive Clustering Hierarchy), uses hierarchical routing model which uses Cluster Head data delivery model. LEACH consists of 2 phases: set-up phase and steady-phase. In the set-up phase, sensors may elect randomly among themselves a local CH with a certain probability. By doing so, the network may balance energy dissipation across the whole network. After the CHs are selected, the heads advertise to all sensor nodes in the network that they are the new CHs. Once the nodes receive the advertisements, they decide which head they belong to. In the steady-phase, sensors sense and transmit data to the BS through their CHs. After a certain period spent in the steady-state, the network goes into the set-up phase again and enters another round of selecting CHs. As we described in section 2,a number of routing protocols have been proposed with the same concept from LEACH (e.g.,[10][11][12][13][14]), and we call them LEACH-like protocols, in which sensor nodes are clustered into groups. LEACH-like protocol is more realistic than the direct diffusion methods because of its using multi-hops to communicate. However, most LEACH-like protocols own the same limitations with LEACH as follow:

- **a.** LEACH assumes that all nodes have enough power to directly communicate with the BS. Such an assumption is not true when the sensor network is applied to a large area.
- **b.** CH nodes communicating directly with the BS, possibly causes channel overload at the BS.
- **c.** Because cluster heads are randomly self-elected, in some areas within the network there may not exist any cluster head.

3.2.1 Multi-hop Data Forwarding in Cluster-based WSNs

In cluster-based wireless sensor networks, Multi-hop data transmission is used for cluster head nodes to transmit data to the BS, where direct communication is not possible due to the distance between them. The solutions to this issue could be grouped into the following two models [4].

- **Multi-hop Planar Model:**

In this model, a cluster head sensor node transmits data to the BS by forwarding its data to one of its neighbors, which is closer to the BS. Following that, in turn the data is sent to a neighbor sensor node which is yet closer to the BS. Thus the information data travels from the cluster head node to neighbor sensor nodes until it arrives at the BS. There are some protocols employing this model, such as [10], [11] and [17].

- **Cluster-based Hierarchical Model:**

In the hierarchical model, the network is broken into clustered layers. Data travel from a lower cluster heads to a higher one. With this approach, the transmission hops from one layer to another by hoping from sensor nodes in different layers, and covers large distance. There are some protocols employing this model, e.g., [18] and [19]. In this paper, we are facing and trying to solve some issues using our proposed routing algorithm, which employs the multi-hop planar model for cluster-based WSNs. Meanwhile, in the concept of our algorithm, only a part of sensor nodes could communicate with the BS directly in their transmission range, and others need routing to find the BS.

4. Proposed Routing Algorithm

This section describes the operation details of the proposed routing algorithm and other features. First,

4.1 Routing algorithm

The operation of our proposed routing algorithm works in rounds. In each round, the BS uses broadcasting to count hop numbers and hierarchicalizes sensor nodes. Then we cluster sensor nodes into clusters, and select transmission routes for data transmission to the BS. Overall, the algorithm is divided into following five steps for conducting the data transmission in one round as following:

Step 1: Counting Hop Number

In this step, broadcasting from the BS is used to count the hop number for each sensor node to the BS. Broadcasting is used, because the same broadcasting message from the BS could reach a sensor node through many routes. After received broadcasting messages, each sensor node uses a routing table to cache all the routes and their hop numbers from the BS to itself in its memory, and then finds out the smallest hop number.

Step 2: Hierarchicalizing Sensor Nodes

Since we want to hierarchicalize sensor nodes into different layers to set the level of sensor nodes, we hierarchicalize sensor nodes depending on the smallest hop number from the BS to each sensor node. Set sensor nodes into one layer which communicate with the BS via the same hope number. In figure 2, we show an image that how the sensor nodes would be organized into hierarchical architecture.

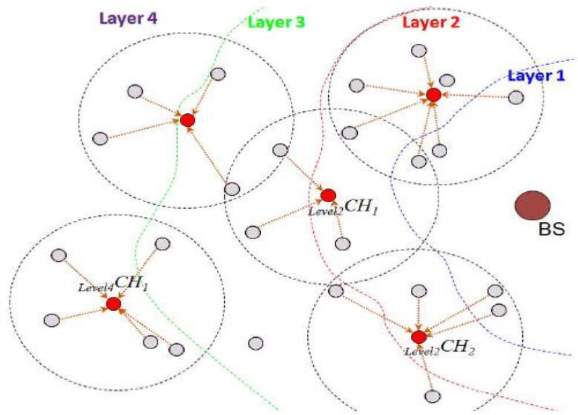

Figure 2: Hierarchicalizing sensor nodes, clustering in each layer

Step 3: Clustering in the System

Use the concept of LEACH Algorithm [3] to decide cluster head (CH) nodes in the system. Shown in Figure 2,since each sensor node has selected a value within 0 and 1 at the beginning of the round, it compares its selected value with a threshold T(n), and decide whether to become the CH or not. If a sensor node becomes a CH node independently, then it announces that to the sensor node near itself by 1-hop transmission. The threshold T(n) is set as follows:

$$T(n) = \begin{cases} \dfrac{p}{p-1(r \bmod (\frac{1}{p})} & \text{if } n \in G \\ 0 & \text{otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots(1)$$

where T(n) is the threshold for node n to decide whether to turn into a CH with the value from 0 to 1. P is a priori determined value that represents the desired percentage of CH nodes during a round (e.g., P = 10%), r is the round number of the current round, we have 20 frames per round, and G is the set of nodes that have not been CH nodes in the last [1/p] rounds.

• For recognize each CH node in their layers, we could mark them as:
Level1CH1, Level1CH2, . . .
Level2CH1, Level2CH2, . . .
• The other non-CH nodes join a cluster using 1 hop communication, depending on the
strongest transmission signal.
• Because there could be sensor nodes that could not find a CH node in their transmission range, so we called them non-clustered sensor nodes.

Step 4: Transmission and Scheduling in Clusters

A CH node schedules all sensor nodes in its cluster with TDMA (Time-Division Multiple Access) medium access control to avoid collision and to ensure the transmission in a cluster, as shown in Figure 3. Then, non-CH nodes could transmit the sensed data to the CH node.

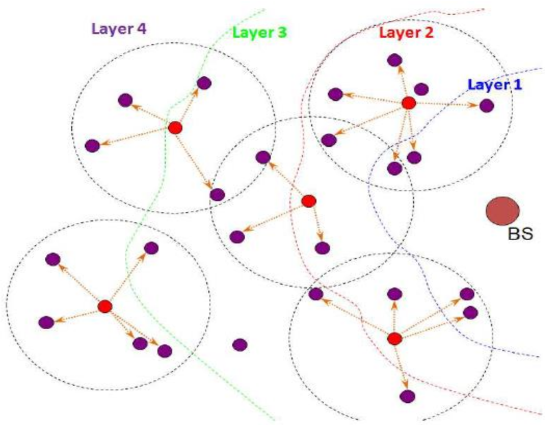

Figure 3: Scheduling with TDMA in the system

Step 5: Selecting Transmission Routes

We establish transmission routes for CH nodes and non-clustered sensor node's data transmission, which concerns:

• First, minimize the hop number.

In step 2, the minimized hop number to the BS for each sensor node has been counted by broadcasting. So, we select the transmission routes with smallest hop number H route.

Hroute = Min {Hi}………….(2)

where Hi is the hop number of route i from a sensor node to the BS.

• Second, maximize the energy in selected routes.

The method is that, calculate the lowest energy node in all routes from the selected routes above with the hop number Hroute. Then, select the route with the highest value of the lowest energy node. The route with the largest Eroute would be the route for transmission.

Eroute = Max {Min {E'ij}}…………..(3)

where E'ij is the energy of the lowest energy node j in route i.

• Third, establish routes for transmission with the method addressed above, for all CH

nodes and non-clustered sensor nodes, as the result in Figure 4.

• Last, discover the alternative sensor node (ASN) while transmitting data. In the next section, we give a particular account of the ASN function. Here, we try to find if there exists an ASN n (Nalt) for the sensor node m near the route. If so, the sensor node m stops routing function and change its state into other states for saving energy.

$$N_{alt} = \left\{ exist \middle| \left(S_{mn} < \frac{R}{2} \right) \cap \left(E_n > E_m \right) \right\} \ldots\ldots\ldots\ldots(4)$$

where S is the distance between two sensor nodes, E is the energy of a sensor node, and R is the transmission range for a sensor node.

• By then, the routing algorithm in one round is accomplished with the five steps described above.

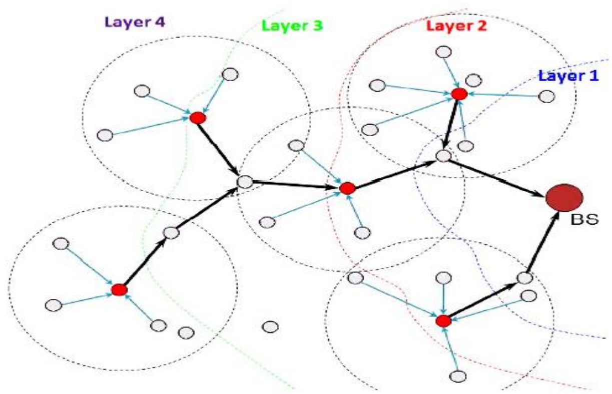

Figure 4: Routing for data transmission

4.2 Alternative Sensor Node

In this paper, we use routing algorithm for selecting the transmission routes. There could be sensor nodes with high energy near the transmission routes. To reduce the possibility of the occurrence to the self-induced black hole problem, we introduce the mechanism of the alternative sensor node (ASN) for a sensor node in its transmission range as follows.

• Suppose that node C transmits with node D via node A, and node B is in the transmission range of A, C, and D.

• Determine the a distance threshold S = R /2 for alternative sensing range, where R is the transmission range for a sensor node.

Here, we talk about the reason why we decide S = R /2 as the distance threshold for ASN operation. Because the threshold should neither be too small nor too large.

Suppose that, if the threshold is determined larger, or nearly the whole transmission range, the routing would lost the ability of communicating with the sensor nodes on the opposite side of the original rout, which is selected for ASN operation. Meanwhile, if the distance threshold is determined smaller, or smaller than one quarter of the transmission range, the ASN operation would lost many opportunities of seeking the ASN sensor node, since the distance for the ASN operation is small. Thus, we decide the distance threshold for the ASN operation as R/2 of the sensor nodes' transmission range.

• Assume that node A finds out node B in its transmission range, and the distance between two sensor nodes A and B is S_{AB}, shown in Figure 5.

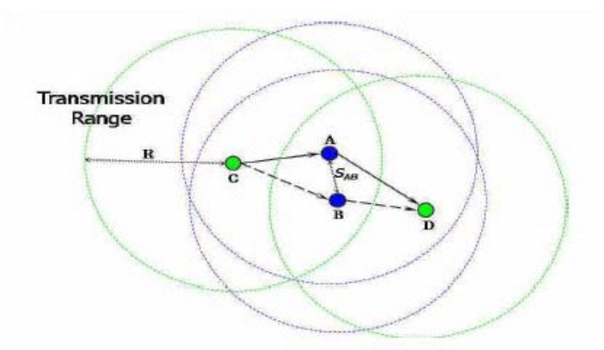

Figure 5: Alternative sensor node B for node A

• If $S_{AB} < S$, and $E_B > E_A$, the node B becomes the ASN of node A. Thus the transmission route from C to D is changed from C → A → D into C → B → D.

In this work, the ASN function is done using broadcasting by each sensor node to its neighbor nodes. From Figure 5 we can see that, after node A broadcasts message to all the neighbor nodes in its transmission range, the node B which fits the requirements of ASN function, returns a message to node A, C and D, thus the new rout is formed. In this method, a sensor node changes the current state into others depending on the ASN operation addressed above. For convenience, we also show the flow chart of our proposed algorithm in round changing system in Figure 6.

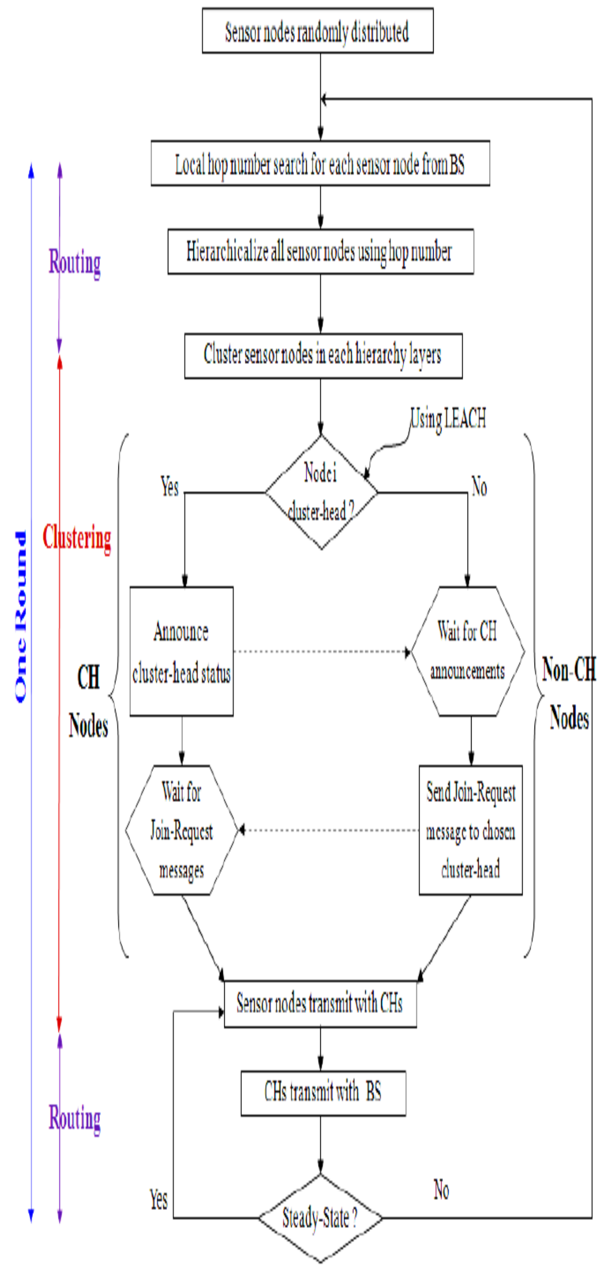

Figure 6: Algorithm flow chart

5.Simulation and Analysis results:

In order to evaluate the performances of our proposed algorithm, the proposed algorithm is simulated with non-clustering routing and simple directed diffusion algorithms using OMNet++. In our simulation experiments, we use a network where 200 nodes were randomly distributed in a 400m × 400m area, Then, two case of WSN' structures are considered for simulation: the BS stays in the center of the simulation field, as well as the BS stays on the margin of the simulation field. Here, we look forward to find a proper desired percentage of CH nodes P during one round. Thus, in the first simulation, P is set as 5%, 10%, 15%, which aims at 5 percent, 10 percent, and 15 percent nodes for CHs per round. The optimum P is expected to obtain the lowest system energy dissipation. The simulation result shows that, P = 10% is assumed to be the optimum percentage of CH nodes, as shown in Figure 7.

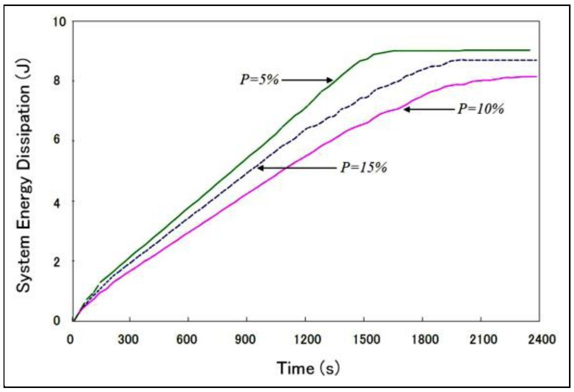

Figure 7: Finding the optimum P with system energy dissipation

5. 1 The BS Stays in the Center of the Field

Table 1: Simulation parameters in OMNet++ (the BS in center)

Map size	400m × 400m
BS position	(200m, 200m)
Number of nodes	200
Transmit range	100m
Node distribution	Random
P	10%
Message packet size	512byte
Node initial energy	0.5J
Energy for data aggregation	5nJ/bit
Communication energy parameter	50nJ/bit
Test items	System lifetime, time of FND

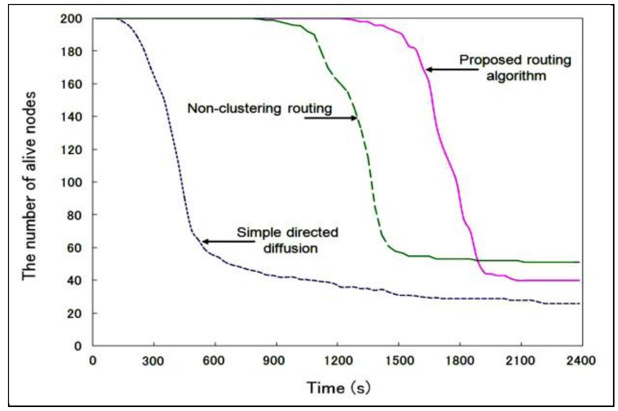

Figure 8: The number of alive nodes in the system with three routing algorithms, where the BS is in the center of the field

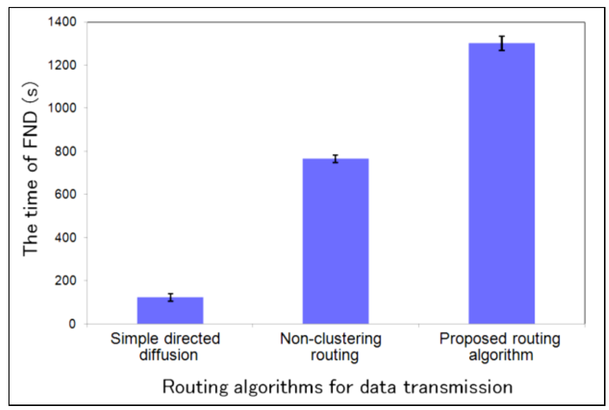

Figure 9: The comparison of system lifetime (the time of FND) in different routing algorithms, where the BS is in the center of the field

5.2: The BS Stays on the Margin of the Field

Table 2: Simulation parameters in OMNet++ (the BS on margin)

Map size	400m × 400m
BS position	(0m, 200m)
Number of nodes	200
Transmit range	100m
Node distribution	Random
P	10%
Message packet size	512byte
Node initial energy	0.5J
Energy for data aggregation	5nJ/bit
Communication energy parameter	50nJ/bit
Test items	System lifetime, time of FND

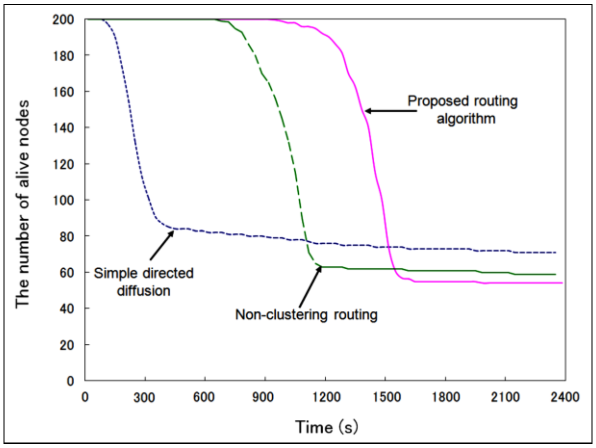

Figure 10: The number of alive nodes in the system with three routing algorithms, where the BS is on the margin of the field

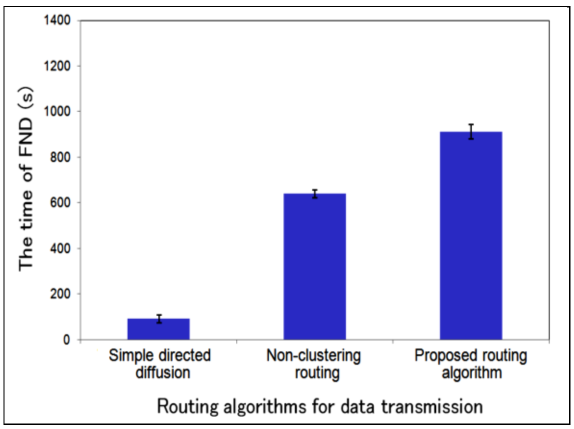

Figure 11: The comparison of system lifetime (the time of FND) in different routing algorithms, where the BS is on the margin of the field

Figure 8 and Figure 10 show the comparison of system lifetime using our proposed routing algorithm versus other two algorithms which are introduced above. Except for the latter parts of the results, the simulation results demonstrate that the system lifetime of our proposed routing algorithm is generally longer than that of non-clustering routing and simple directed diffusion. However, because of the self-induced black hole problem, from the Figure we can see that, the result becomes into nearly straight line near the end of the simulations. The reason is that sensor nodes in certain part of the system (far away from the BS) could not transmit the data packets to the BS, since the intermediaries died already for multi-hop transmission to the BS.

A *confidence interval* gives an estimated range of values which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data [20]. We applied confidence Intervals to our simulation results, and the certain percentage (confidence level) is set to 95%. Figure 9 and Figure 11 present the time when the *first node dies* (FND) in different data transmission algorithms, which also indicates the balance of energy consumption in the system. The results demonstrate that our proposed routing algorithm has a better energy consumption balance in the system than the other two, especially, times better than simple directed diffusion, because the FND appears the latest in our proposed routing algorithm.

6.Conclusion and Future Work

In this paper, we have introduced a novel power efficient routing algorithm for hierarchically clustered WSNs. The simulation results show that, compared with simple directed diffusion and non-clustering routing algorithm, our proposed routing algorithm prolongs the system lifetime for large scale multi-hop transmission WSNs. Our future plan includes the improvements to our simulation experiments with more variations for better comparison results, such as changing the position of the BS, and changing the probability of becoming CHs from all sensor nodes. Then, we will consider more about the issue to the self-induced black hole problem in the multi-hop transmission.

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